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LED SHIPBOARD LIGHTING: A COMPARATIVE ANALYSIS

by

Aaron Troy Freymiller

December 2009

Thesis Advisor:	Nicholas Dew
Second Reader:	Bryan Hudgens

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LED SHIPBOARD LIGHTING: A COMPARATIVE ANALYSIS

Aaron Troy Freymiller
Lieutenant, United States Navy

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requirements for the degree of

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Author: Aaron Troy Freymiller

Approved by: Nicholas Dew
Thesis Advisor

Bryan Hudgens
Second Reader

Dr. William Gates
Dean, Graduate School of Business and Public Policy

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ABSTRACT

This thesis attempts to answer the question provided by the Office of Naval Research (ONR) as to "why LEDs, given their better efficiency, reliability, and maintainability are so difficult to implement in the Navy with an emphasis on shipboard use." This project gives a brief background into LEDs and gives a critical look into the cost benefit analysis (CBA), from maintenance costs to military specifications, in an attempt to provide a more realistic CBA using a hybrid approach. In addition, to focus on hard quantifying benefits, such as productivity and health benefits, from switching to better quality lighting fixtures. Also examined are the organizational barriers affecting innovation takeoff of LEDs implementation within the Navy.

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LIST OF ACRONYMS AND ABBREVIATIONS

ATC	Affordability Through Commonality
COTS	Commercial off the Shelf
CVN	Aircraft Carrier Nuclear
DDG	Guided Missile Destroyer
DoD	Department of Defense
DOE	Department of Energy
DON	Department of the Navy
DVD	Digital Video Disk
EISA	Energy Independence and Security Act
GAO	Government Accountability Office
ISO	International Organization for Standards
LED	Light Emitting Diode
LHD	Amphibious Assault Ship
LUX	Luminous Intensity
Mil Spec	Military Specification
NPS	Naval Postgraduate School
NSSC	Naval Sea Systems Command
ONR	Office of Naval Research
RAC	Risk Assessment Code
ROI	Return on Investment
S&T	Science and Technology
SSL	Solid State Lighting
SSS	Shipbuilder's Special Study
USN	United States Navy

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I. INTRODUCTION

A. GENERAL

The Office of Naval Research (ONR) is known for its robust science and technology (S&T) program with testing and implementation to meet war fighter's requirements. They do this by offering grants and stipends to businesses, schools, or laboratories to research commercial or new technology breakthroughs that could benefit the Navy.

Larry Schuette, Director of Innovation at ONR, recently approached the Naval Postgraduate School (NPS) to analyze some issues related to the implementation of innovations within the USN. This study addresses one aspect of ONR's request.

B. OBJECTIVES OF RESEARCH

As part of its effort to reduce the life cycle costs of its fleet using Affordability Through Commonality (ATC), the Navy is investigating commercial lighting innovations while reducing its energy consumption and minimizing its carbon footprint. In doing this, the Navy is estimating the cost of implementing LEDs onboard Navy ships and has asked NPS to assist in researching the viability of retrofitting the Navy fleet with newer lighting technology.

C. RESEARCH QUESTION

The research project provided to NPS by Dr. Larry Schuette asks, "Why is LED technology, which has proven benefits within commercial sectors of reducing costs and energy consumption, so difficult to implement within the Navy with an emphasis on shipboard operations?" In conducting research for this project, I felt that in looking at the barriers to implementation, along with a CBA, would best provide Dr. Larry Schuette the answers to the questions asked by ONR.

D. SCOPE

This project will assess the cost benefit analysis (CBA), provided by a co-researcher, comparing the life cycle costs of equipping the U.S. Navy surface and submarine fleets from fluorescent lighting fixtures to LED lighting. Although there are a wide variety of shipboard lighting fixtures currently in the fleet, this project will concentrate on general illumination fixtures, replacing overhead fluorescent fixtures to LED equipped replacements.

I will examine benefits not normally included in the CBA to provide ONR a more realistic analysis of implementing LEDs onboard navy ships. With this hybrid approach, I intend to show ONR that although some benefits are difficult to quantify, to disregard these would fail to provide a true measure of benefits to the organization.

E. METHODOLOGY

Part of the review focused on the CBA provided by a fellow colleague at the Naval Postgraduate School also conducting research for ONR on shipboard LED implementation. I will examine benefits not normally included in the CBA to provide ONR a more realistic analysis of implementing LEDs onboard Navy ships. With this hybrid approach, I intend to show ONR that, although some benefits are difficult to quantify, to disregard these fails to provide a true measure of benefits to the organization.

F. ORGANIZATION OF RESEARCH

I have organized this document to facilitate the reader's understanding and comprehension of the research conducted through the following chapters.

Chapter I, Introduction, presented the purpose of this research, the research questions and the scope and limitations of the analysis performed.

Chapter II, Background, provides the reader information on lighting advancements and the technology behind LEDs.

Chapter III, Business Case Model review, provides figures to demonstrate to ONR, which ships would benefit from a retrofit to LEDs. In addition to the CBA, this chapter suggests to ONR any changes that could be implemented to ships failing the CBA model.

Chapter IV, Intangible Benefits, attempts to quantify overlooked benefits beyond just that of the costs reductions from implementing LEDs on ships.

Chapter V, Conclusions and Recommendations, provide ONR the findings and recommendations on the research conducted. This chapter also includes areas of further research to be conducted in widening the scope of LED implementation within the Navy.

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II. BACKGROUND

A. HISTORY OF LEDS

This chapter provides a brief background into the development of LEDs. This chapter first provides the origins of LEDs, how they came about, who invented them, and provides examples of how LEDs have made their ways into our everyday society and eventually onto ships. This section also provides advantages and barriers to implementing LEDs onboard ships.

The LED is a key component in today's lighting technology. Modern households use LEDs in such components as digital video disc, (DVD) readers, televisions, and even cars. Who invented LEDs, and when were they invented? The answers to those questions remain somewhat vague.

In 1962, four research groups in the United States reported a working LED semiconductor laser, about which several papers were published by Robert Hall and Nick Holonyak (two General Electric Company employees), along with Marshall Nathan of IBM and Robert Rediker of MIT. These names are displayed on the Hall of Fame for optoelectronics. However, there is one forgotten figure, referred to as the pioneer of semiconductor research, a stepping stone to today's solid state lighting. Oleg Vladimirovich Losev, a young Soviet scientist working as a technician in radio laboratories, published 43 papers to Russian, Britain, and German research journals receiving 16 patents for his semiconductor research (Zheludev, 2007).

Losev made numerous discoveries in solid-state electronics, which included the first solid-state semiconductor amplifier and generator. In 1924 The Wireless World and Radio Review magazine wrote, "Mr. O. Losev of Russia has in a comparatively short space of time achieved worldwide fame in connection with his discoveries" (Zheludev, 2007). However since his death in 1942 his contributions towards solid state lighting have been overlooked as broader research continued within the community (Zheludev, 2007).

B. HOW HAVE LEDS FOUND THEIR WAY ONTO SHIPS?

LEDs were first introduced into the private sector as traffic signals and exit signs, since the first generation LEDs were monochromatic. It was not until manufacturers began using ultraviolet LEDs, which excited phosphors emitting white light and other colors, that LEDs took off.

The benefits of LEDs over incandescent bulbs are that LEDs use less power to illuminate, and they last longer. To put this in perspective, a typical 60-watt incandescent bulb has an output of around 800 lumens and lasts about 1,000 hours; while GE has announced white LED lighting products with efficiency of 30 lumens/Watt and 50,000 hour life (Talbot, 2003). According to the International Organization for Standards (ISO), the standard luminance for an office work space is 200-100 lux (Tanaka, Komine, Haruyama, & Nakagawa, 2003). The difference between lumen and lux is that lux takes into account the area over which the luminous flux (light intensity) is spread, while the lumen is the measure of the power of light perceived by the human eye. For example a luminous flux of 1000 lumens, concentrated over an area of one square meter lights up that area with an illumination of 1000 lux. While that same 1000 lumens spread over a ten square meter produces only 100 lux.

Today's white LEDs come in two different types, as referenced here with Figure 1. These two types are one-chip and multi-chip LEDs. One-chip type LEDs work by applying current across a blue LED chip that produces a blue light and adding yellow phosphor to create white light. Multi-chip type LEDs work by using the primary colors of green, red, and blue chips simultaneously, to create a white light (Tanaka et al., 2003).

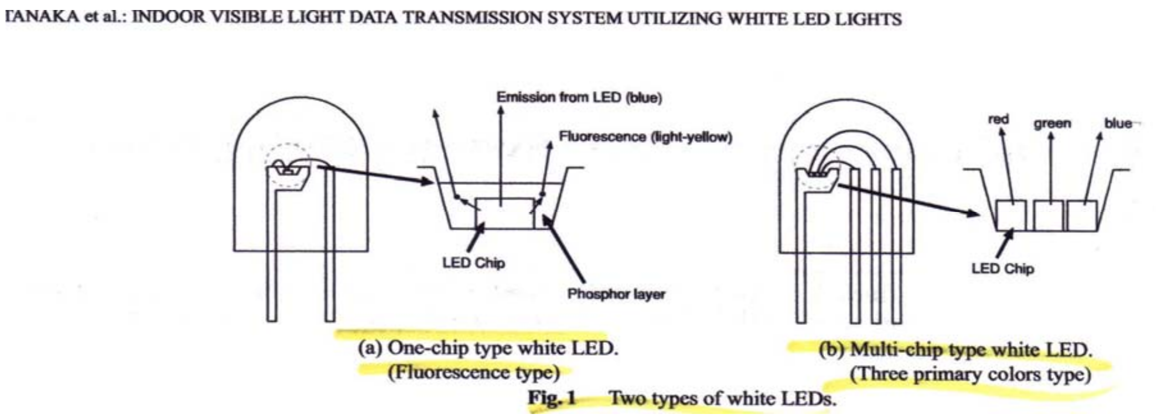

Figure 1. Two types of white LED chips (From Tanaka et al., 2003)

LEDs are considered the next generation in lighting and are categorized by two properties: luminous intensity and optical power "Luminous intensity is the unit that indicates the energy flux per a solid angle, and is related to the luminance at an illuminated surface. This is generally expressed as the brightness of the LED. Optical power is defined as the total energy that is radiated from an LED" (Tanaka et al., 2003).

1. LED Advantages

LEDs have several advantages over incandescent bulbs. LEDs do not have a filament that will burn out, which allows them to last longer. LEDs are constructed to focus light in a particular direction, compared with fluorescent lights, which omit light omi-directionally, creating wasted light. Most diodes are inefficient, while ordinary diodes use a semiconductor material, which ends up absorbing a lot of the light energy, whereas LEDs are specially constructed to release photons outward (How Stuff Works, 2009). Looking at Figure 2, gives an illustration of how LEDs diodes work and how the construction of these bulbs focuses light.

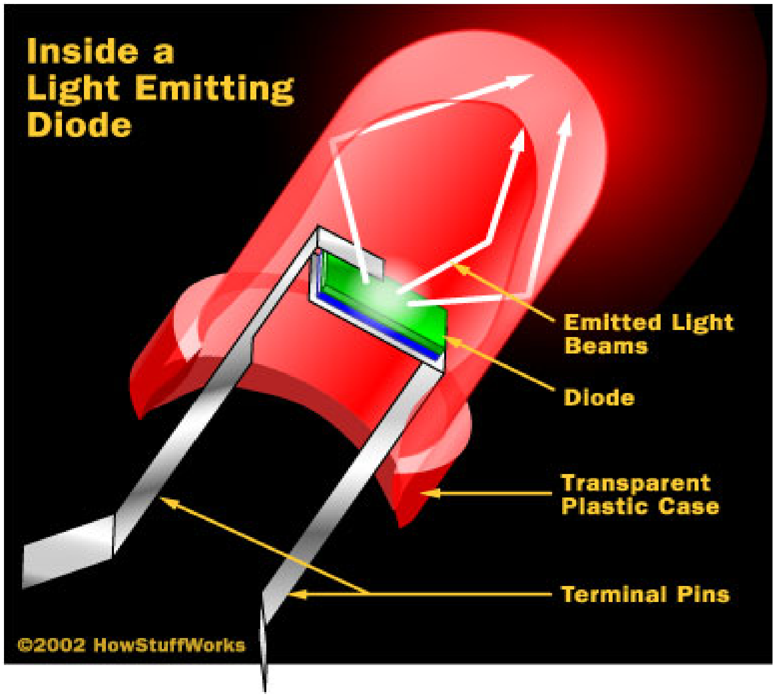

Figure 2. LED Light Diagram (From How Stuff Works, 2009)

The main advantage that LEDs have over incandescent bulbs is efficiency. Producing light also involves generating heat by warming up the filament. This is a complete waste of energy since some portion of available electricity is not going towards producing visible light, but rather, is required to produce the heat. LED's generate very little heat compared to incandescent lights, since there is no filament to heat up: therefore, a greater percentage of electrical power is going directly into generating light, cutting down on electricity demands (How Stuff Works, 2009).

2. Implementation into the Navy Fleet

Given the demands of the United States Navy, there is always a growing effort to reduce costs wherever possible. One aspect of cost-savings that the Navy is exploring, is replacing current shipboard lighting with LEDs. Unfortunately, you cannot just put these commercial off-the-shelf (COTS) bulbs on a ship. These bulbs have to undergo a military transition to be implemented into the fleet. They must be tested and modified to meet ship lighting fixtures, specifications must be written as to technical data, and publications must be written both for handling and for required inspections. Finally, the

Navy must consider LED's entry into the supply chain, and contracting and funding issues that may arise during the implementation of the new lighting system.

For example, one of the biggest hurdles discovered after trial tests of LED lighting, conducted by L.C. Doane Company in the well decks of USS WASP (LHD 1), was the addition of the MIL-DTL-16377 (Mil-Spec 16377), to the MIL-DTL-16377H. Dated August 2, 1996, this provides general specifications of lighting fixtures, and associated parts for shipboard use, along with a listing of supplemental specifications for implementing solid state lighting SSL/LEDs aboard ships. These more restrictive standards caught many vendors off-guard while performing research and development (R&D) for general illumination lighting. Since adoption of these new specifications, NAVSEA has implemented a Navy SSL/LED road map showing shipboard installations beginning in 2010–2013.

C. WHAT BARRIERS ARE AFFECTING LED TAKEOFF?

There are always barriers to implementing newer technology such as:

- Contracts
- Entrenched programs
- Funding
- Push back

Multi-year contracts may be awarded for older technology, reducing the benefit of implementing newer technology, otherwise, old contracts would have to be reduced at an additional cost to the CBA. In addition, programs tend to become entrenched, such as supply lines that require additional support, or requirement office's preferences to do business with certain companies. Funding is an issue for any organization. How much and for how long do you set aside funds to grow technology? Since some programs fail to mature, there is always an opportunity for costs to be revised by choosing one technology over another. Since the Department of Defense (DoD) has a 20% share of the Federal budget, each service strives to get the best bang for the buck in regards to their return on investment (ROI). Push-back within organizations comes in two forms: internal and external. Internal resistance can come from employees within the

organization—some support the new technology while others prefer the status quo. External factors come from outside the organization and can include such things as providers of existing products slowing down the acquisition process with court proceedings, or simple procedural delays, which can discourage the company from pursuing improved technology.

III. THE BUSINESS CASE MODEL: A DIFFERENT LOOK

A. OVERVIEW

This business case outlined by a fellow NPS colleague gives the break-even analysis by ship class. According to this model, only five out of 13 ships benefit from the retrofit to LED lighting, given the assumptions and current estimated costs of LED fixtures shown here in Figure 3.

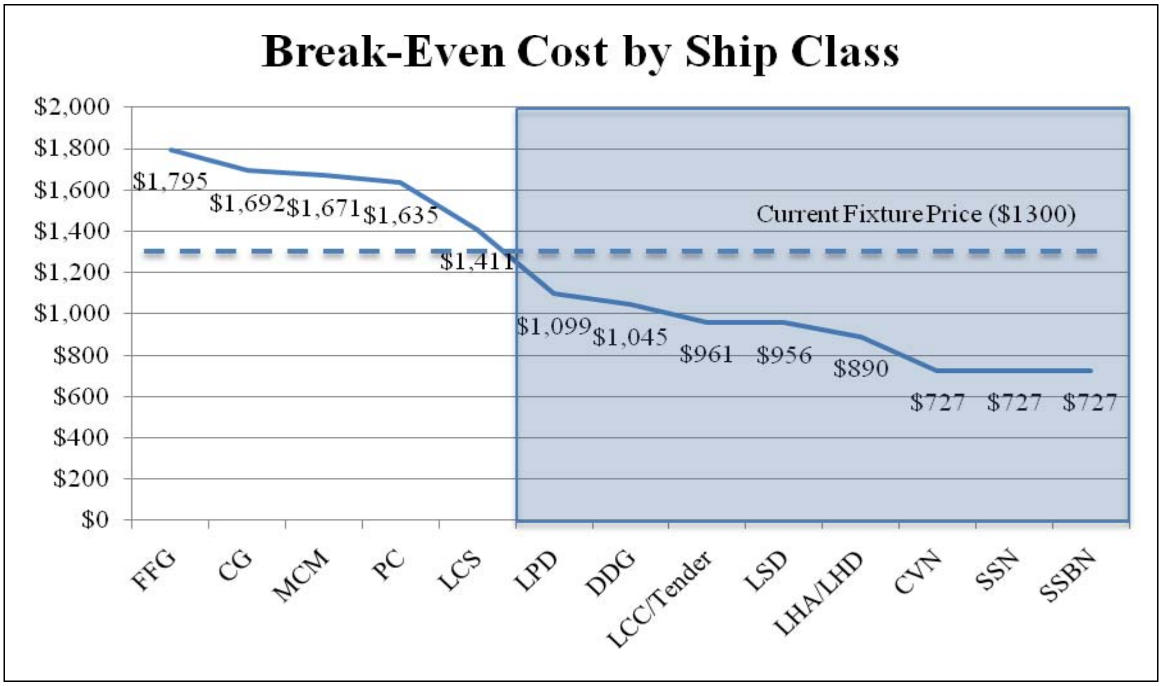

Figure 3. Break Even Analysis by Ship Class (From Cizek Master thesis, 2009)

Some assumptions included in Figure 3, which will be examined further, are maintenance costs and Mil-Spec issues.

1. Maintenance Costs

Maintenance costs are those that include labor to replace burnt-out lamps, materials, and components. These costs used the average hourly rate based on the 2010 Department of the Navy average composite standard pay rates for pay grades from E-1 to E-4, which were then averaged. The issue for hourly pay, which was used to construct

this figure, is not the issue. When considering maintenance costs the problems lies with estimating labor hours, the assumption of 30 minutes of average time per lamp replacement may be too conservative. A study conducted by the USS George Washington (CVN 73) found the average time to replace fluorescent fixtures to be 86 minutes. Although there are various ship sizes within the Navy, there is no conclusive evidence on the amount of time it takes to conduct maintenance on fluorescent fixtures, nor is it mandatory to track the amount of ballasts, starters, or bulbs replaced on any given ship, let alone tracking the maintenance time involved in tagging, troubleshooting, travel time to and from ships, or replacement of the fixture. This lack of information hinders the true benefits to switching from fluorescent to LED fixtures.

A phone conversation with Ed Markey from the Naval Sea Systems Command (NSSC), revealed that there is no written requirement by NAVSEA to tag fixtures for replacing light bulbs. However, with safety concerns the requirement to continue tagging non-working equipment was left to the discretion of the Commanding Officer. Markey advised that there are several ships still conducting tag-outs, which were not necessarily required, incurring additional unnecessary maintenance expenses. This increased maintenance cost and better estimates on bulb, starter, or ballast replacement could improve the break-even analysis by allowing more just five ships to benefit from LED retrofits.

2. Mil-Spec 16377 Issues

In efforts to streamline lighting onboard ships, the Navy added to the general illumination lighting specification onboard ships to include LED lights. This new specification attempted to establish affordability through commonality (ATC) in efforts to standardize LED shipboard requirements to drive down costs standardizing manufactures requirements for LED lighting onboard ships. However, this military specification falls short in several categories, Mil-Spec 16377 only establishes performance standards as to luminaries output, vibrations, and heat requirements but fails to provide power or design requirements. Currently, light-pod is the first general illumination solid-state lighting (SSL) fixture to receive full shipboard qualification from NAVSEA. In July 2009, Light-pod installed ten fixtures as part of the Shipbuilder's

Special Study (SSS) in conjunction with Bath Iron Works on DDG—108 (Wayne E. Meyer), thus far the installed lights has had no noticeable power savings as recorded by the ship. Another issue is that Northrop Grumman is currently in the process of manufacturing LED lighting to compete with Light-pod, although both companies will meet the military specifications established by NAVSEA, neither lighting design or the power modules are interchangeable, thus reducing the savings benefits by stocking several manufactures parts and increasing the complexity of the supply distribution.

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IV. INTANGIBLE BENEFITS

A. WHAT IS NOT INCLUDED IN THE BUSINESS CASE

Most business cases for innovation include benefits from cost savings as to the benefits of implementing the latest technological advances. However, there are more benefits than just the cost savings that should be included in the arguments as to whether the new technology should be implemented. Such benefits are sometimes hard to quantify, since there have not been many studies to quantify these intangible benefits.

In the previous chapter we took at look at LED lighting and compared them to fluorescent lighting and showed that LEDs are: brighter, more efficient, require less maintenance and are less expensive to operate compared to the 1930's style fluorescent lighting. According to the break-even analysis in the previous chapter there are currently only five classes of ships that are beneficial to retrofitting to LEDs. However, you find yourself asking the question "How do we improve on the costs of LEDs to capture a greater portion of ships to retrofit?" You can change assumptions, and try your best to look into the crystal ball in evaluating what fuel prices may be in the future to achieve better cost estimates—or how the costs of LED fixtures will decrease overtime—but what can you add to your business case that has been left out, that could be a better foundation to achieving your answer?

In this section, I will be looking at just what can be added to this business case that makes it an even better reason to why the Navy should implement LEDs onboard ships, particular focus areas are:

- How to drive down the costs of LEDs
- Lighting effects on productivity
- Health benefits related to better lighting

B. DRIVING DOWN THE COSTS

There are several ways to drive down costs with new technology:

- Wait
- Buy in bulk
- Promote competition

1. Waiting

The waiting game is an easy and inexpensive concept: essentially, you wait until the price of the unit falls for any variety of reasons. The price drop can be because of industry maturity, more people buying the product, possibly a competitor selling a similar product decreasing your market share or possibly you could have a situation as technology changes driving down the costs of older models. A case in point is the i-Phone, distributed by the Apple Company in June 2007, which sold for $599 dollars; in September 2007, that price fell by $200 dollars because of market forces (Apple, 2007). Waiting, in this particular scenario, saved 33% just to wait for three months. Here there were no technological advances, just the demand that drove down the costs; but, as you follow the i-Phone progression you can see how the price dropped for older technology items and as the 3G and 3Gs upgraded models came out, the price dropped for the previous models.

In any organization such as the Navy, there are always benefits and costs with every decision. If you purchase now, you gain an edge in technological advances such as buying a new weapon system, but as we see above you lose out, since buying at the height of the market and failing to recognize the cost benefits of waiting until maturity. For some organizations such as the Navy, waiting is not always the best answer. The Navy is a very specialized customer, and whether designing a new weapon system or adapting technological advances, all have to meet specific guidelines, which are not necessarily adaptable to commercializing to the general market. Therefore, the Navy cannot recognize the benefits of increased market share to the commercial sector since its specifications are too great for general applications.

2. Buying in Bulk

Buying in bulk provides your biggest opportunity in saving money. This happens because the more you purchase of a particular item the greater quantity reduces your cost per unit for every item purchased. For example if the government wanted to purchase 25,000 M-16s for a total cost of $30 million dollars, it would pay $1200 per unit; but, if the quantity of M-16s was increased to 30,000 units, the government would save $200

dollars per unit. This buying power of purchasing in bulk provides incentives for the manufacture to drive down costs to win a bid for providing the government the equipment they need for a nominal price. If you look at the purchasing power of commercial entities such as Walmart, you can see the huge advantage that Walmart has from leveraging their providers to get a product at the best possible price. This savings is then partially given to the customers at lower costs than many of its competitors.

The Department of the Navy (DON) however is a small organization compared to commercial sectors or DoD as a whole. With less than 300 ships, the Navy by itself has very little room to leverage its providers in getting the best price possible from its suppliers. The Navy normally relies on industry to achieve leveraging normally in the form of competition.

The military is also different from the commercial sector as the way it uses funds. The Navy unlike the commercial sector cannot just issue stock or receive additional loans; it has to use their portion of government appropriation allotted to them by Congress. The Navy also has to abide by Fiscal Law, which constrains the Navy's ability to receiving economic benefits of buying in bulk. According to Federal Appropriations Law chapter 5, section B sometime called the "bona fide needs statue, provides that the balance of a fixed-term appropriation "is available only for payment of expenses properly incurred during the period of availability or to complete contracts properly made within that period…." (GAO Redbook, 2004). What this bona fide need tries to accomplish is tying the hands of Congress to future obligations, when the need for those funds are in future years. For example, the Navy cannot just purchase additional computers to replace existing equipment that will need to be replaced in five years because this violates the bona-fide needs rule, the expense is in future years. This hurts the Navy's purchasing ability of buying in bulk, if it cannot justify the need for that equipment for the current fiscal years funds.

3. Promote Competition

The DoD is great source of economic stimulus for many companies; whether it's purchasing or updating airplanes, ships, or facilities, the government invests a lot of time

and money to get the best deal possible. It has been known that promoting competition drives down costs, currently the Department of Energy (DOE) has established the L-prize as part of the Energy Independence and Security Act of 2007 (EISA) encouraging the development of energy efficient solid-state lighting (SSL) to replace the most common lighting products used in the United States to include a 60-watt incandescent and PAR 38 halogen incandescent lamps with the winning manufacture receiving a $10 and $5 million dollar awards for 60-watt and PAR 38 lamps respectively. (DOE, 2009)

The Navy could use similar incentive plans like the L-Prize in promoting competition between manufactures, since there are currently only a few suppliers of LED shipboard lighting manufactures and installers that can meet the requirements of Mil Spec 16377 (DON, 2008).

One situation that the Navy could use in promoting competition for LEDs is to use head-to-head competition between manufacturers; this could be done by allowing a multi-year engineering demonstration on specific ships between manufactures. This could easily be done by dividing the ships into sectors in which manufactures could display their lighting in these sectors. This would allow the Navy to easily monitor specific sectors such as port (left) or starboard (right) sides of the ship. Since ships are relatively identical between port and starboard, this would not give one manufacture a competitive advantage over the other. This type of demonstration would also show to the manufactures that the Navy is serious in implementing lighting technology with a multi-year demonstration seeing the benefits provided by the manufactures in reducing the energy consumption and its carbon footprint. This multi-year long demonstration would also allow the sailors onboard the Navy vessel to conduct tests and see how just how much the Navy could benefit from installing LEDs on ships, with the winner getting a contract in converting the Navy fleet over from fluorescent to LED lighting.

C. LIGHTING EFFECTS ON PRODUCTIVITY

Ever since the invention of the light bulb by Thomas Edison there have been numerous studies trying to link lighting to productivity. Some of the earliest studies were conducted in the 1920s, trying to link lighting to productivity from cases such as silk

weaving (Elton, 1920) to the Hawthorne experiments in 1927. While debates continue today on whether lighting effects productivity, most researchers would agree with the argument that without light productivity would be close to zero (Boyce, 2003). However, before you can link lighting to productivity you must first define productivity and the effects that productivity has on human performance. Peter Boyce has determined that there are three ways in which lighting can affect human performance, as seen in Figure 4. These are the visual, circadian, and perceptual systems (Boyce, 2003). This conceptual framework shows the difficulties that studies have in trying to conclusively link productivity to lighting.

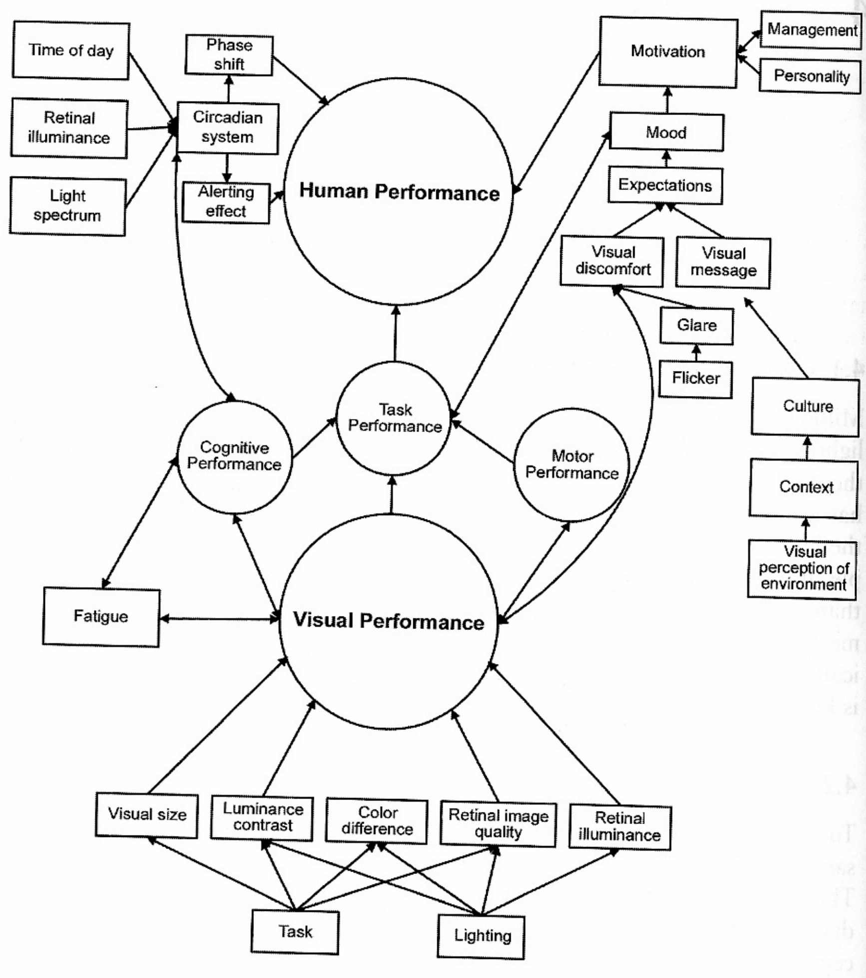

Figure 4. Conceptual framework showing how lighting conditions can influence human performance (From Human Factors in Lighting (Boyce, 2003)

1. Visual Performance

Visual performance if probably the easiest to understand: we need light in order to complete the assigned tasks. Visual performance, as defined by Smith is the ability of the eye to carry out a particular visual task with both speed and accuracy. It is dependent upon the level of prevailing luminance; the relationship is one that follows the law of diminishing returns (Boyce, 2003). According to Boyce visual performance are divided into the five sections, which are visual size, luminance contrast, color difference, retinal image quality, and retinal luminance. These five areas relates the object to be seen to that of the background against the object and the lighting differences between the object and background makes up the visual stimulus of the object presented to the visual system.

While these tasks are related, it is the visual system that contributes to task performance. Boyce states that "task performance is the performance of the complete task. Visual performance is the performance of the visual component of the task" (Boyce, 2003).

Looking at these arguments in relation to the Hawthorne experiments, shows that the task performance of winding wires on the spool had little visual performance towards the completed tasks; which is to say that these learned tasks took very little visual performance, and even when the light decreased from 110 lx to 11 lx, the task could still be completed, even though complaints and productivity decreased around 33 1x. This dynamic is evident in many trained visual tasks; take type writing, for example. Even thought this task is a visual one, a trained typist rarely looks at the keyboard when typing and this task could be completed essentially in pure darkness; however, mistakes would be difficult to detect without adequate lighting levels.

Although the Hawthorne Experiments were shown to have low visual performance, there are other jobs that require greater amounts of visual performance. In the military, we use a risk assessment code (RAC), as in Table 1, to express the risk by combining the elements of hazard severity and mishap probability. An event could have a large probability of occurring but the severity of the incident very low, what this chart tries to mitigate is having a large probability mirrored with a great severity. Looking at

the Hawthorne experiment through the eyes of this chart it would fall into category of 4 to 5 with the severity of the injury minor but the probability of the incident occurring increasing as the lighting level diminishes. However, when looking at the Buchanan experiment of the effects of increasing luminance from 485 to 1,570 lx decreasing the error rate of filling the pharmacist's prescriptions from 3.9 percent to 2.6 percent (Buchanan et al., 1991) would have a RAC code of 2, the probability of the event occurring is pretty low, but the severity of the actual event should it occur is very high and possibly life threatening.

Risk Matrix

		Probability			
		A	**B**	**C**	**D**
Severity	**I**	1	1	2	3
	II	1	2	3	4
	III	2	3	4	5
	IV	3	4	5	5

Table 1. Navy's Risk Matrix (From OPNAVINST 3500.39B)

RAC Definitions:

- Critical risk
- Serious risk
- Moderate risk
- Minor risk
- Negligible risk

When looking at assigned tasks, it shows that some jobs require greater visual performance than others when considering the severity of the outcome, should something go wrong. It also shows the value that lighting has on visual performance, such as the case from Allentown, PA, where changing the lighting in a Pennsylvania Power & Lighting Company's drafting room decreased glare and increased productivity by at least 7.5 percent (Wareham, 1990).

2. Circadian Performance

Circadian performance is most notably known by many to be the sleep-wake cycle in humans. This sleep wake-cycle looks at the rhythms of sleep-wake over a 24-hour period, shown in Figure 5. Before lighting was invented, workers worked during the sunlight hours and slept during the moonlight hours. However, since the invention of the light bulb, we as a society have looked at how to stretch or shift this sleep-wake cycle.

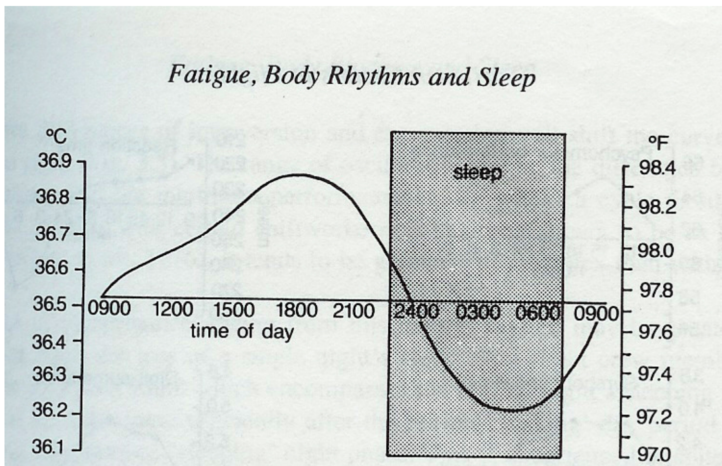

Figure 5. Circadian Cycle (From Human Factors in Flight, 1993)

In this diagram, you see that this sleep-wake cycle follows the internal clock of the sun and moon cycle. Even with strict guidelines, aviation pilots have admitted to falling asleep while flying the aircraft on both short and long trips. While trying to mitigate these problems there has been success in changing the lighting system over to one that closely resembles daylight illumination in efforts to shift or reprogram the sleep-wake cycle. Many studies have shown that exposure to light is the principal stimulus to the human circadian system (Dijk et al., 1995)

3. Perceptual Performance

The perceptual performance comes into play after processing the image by the visual system (Boyce 2003). The output of the perceptual performance deals with a sense of visual discomfort leading to mood and motivation changes in mundane and tedious prolonged work. As in the Hawthorne experiments, we can see how perceptual

performance affected productivity in the workers, while conducting work in poor lighting conditions, by complaints given by employees about the light quality in the work environment.

D. HEALTH BENEFITS TO BETTER LIGHTING

Lighting is necessary for the visual system to operate but if used or installed wrong can lead to health issues such as eyestrain or fatigue. Lighting conditions have been show to lead to eyestrain from inadequate luminance for the task (Simonson & Brozek, 1948) and lamp flicker even if not visible (Wilkins et al., 1989). In Figure 6, we relate fluorescent lighting to the frequency of headaches occurrences depending of the type of ballasts used. Here we see that by switching from magnetic to electronic ballasts decreased the weakly incidences of headaches. Currently, the U.S. Navy still uses magnetic ballasts onboard ships and by changing the lighting system onboard ships could lead to less eyestrain and headaches, increasing productivity, while improving the quality of the work environment.

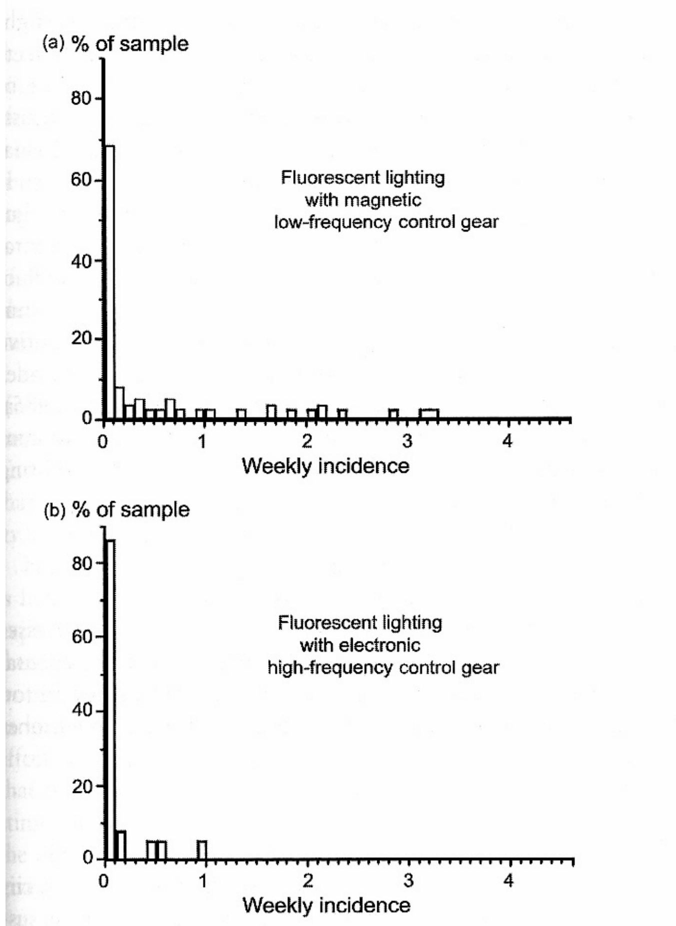

Figure 6. Lighting Ballasts relating to headaches (From Human Factors in Lighting Boyce, 2003)

Although these intangible benefits are difficult to quantify, it is human capital that is the costliest expense to any organization. In regards to any CBA, a hybrid approach should be used to include our greatest assets.

V. CONCLUSIONS AND RECOMMENDATIONS

In conclusion of my research, to answer the question sought out by ONR as to "why it is so difficult to implement LED technology onboard Navy Ships," is that in any organization you are limited by the resources you have, and difficult choices have to be made to best utilize those resources. Even if the CBA or hybrid approach is used showing the organization that implementing LEDs onboard Navy vessels would make economical sense, battling the Navy's organizational structure for funds and priorities is the road block that LEDs face against rapid implementation within the Fleet. This is evident when looking at the Naval fleet in seeing that magnetic ballasts and T-12 lamp fixtures are still being used, while the rest of the commercial industry are using electronic ballasts and T-8 equivalent fixtures.

It is not until outside influences, such as energy efficiency, additional funds, or pressure from the top, that shifts began to happen from the organizational structure to include the upfront costs to retrofit existing Navy vessels from fluorescent fixtures to LED. As seen in the case of the Marine Corps and Army's MRAP program, the shifts didn't take place until outside influences and top officials began reorganizing priorities to increase the scale of operations.

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APPENDIX A RESIDENTIAL LED LIGHTING

L11a Residential LED Lighting

Description	For porch fixtures, under-cabinet lighting, under-shelf lighting, and task lighting		
Market Information:			
Market sector	RES		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET, ROB		
Basecase Information:			
Description	Standard A-line lamp		
Efficiency	75	watts w/ 1150 lumens or 15 LPW	
Electric use	82	kWh/year	Assumes 3 hours/ day for res usage for 365 days/yr
Summer peak demand	0.005	kW	
Winter peak demand	0.015	kW	
Gas/fuel use			
New Measure Information:			
Description	White LED lamp		
Efficiency	28.75	Watts @ 40 LPW	
Electric use	31	kWh/year	Assumes 3 hours/ day for res usage for 365 days/yr
Summer peak demand	0.002	kW	
Winter peak demand	0.006	kW	
Gas/Fuel use			
Current status	PROTO/FLDTEST		
Date of commercialization	2004		
Life	13	years	or 10,000 hrs
Savings Information:			
Electricity	51	kWh/year	
Summer peak demand	0.003	kW	
Winter peak demand	0.009	kW	
Gas/Fuel		MMBTU/year	
Percent savings	62%		
Feasible applications	12%		Percent of lighting energy use apps < 3hrs/day
2020 Savings potential	22,682	GWh	
2020 Savings potential	229	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$58	2003 $	Currently at $.20/lumen. Estimated to go down to $.05/lumen by 2010
Other cost/(savings)	($1)	$/year	Avoided lamp replacement costs
Cost of saved energy	$0.114	$/kWh	
Cost of saved energy	$11.26	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	High inc.cost; thermal management, LED systems & components design		
Effect on utility	Less bulb changing		
Current promotion activity	PIER, DOE, Manufacturers selling to selected commercial/industrial reps		
Rating	2	(1-5)	
Rationale	Manufacturer support, but high incremental cost; Other markets likely to be more attractive for LEDs		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Continue research on improving white color & raising LPW for white; develop business case; education for lighting des		
Sources:			
Savings	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Peak demand			
Cost	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Feasible applications	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Measure life	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Other key sources	Sandy David-TCP, Inc. 330-995-6111; Vernica Martinez-LumiLeds, 408-435-6111		
Principal contacts	Judie Porter, PIER Lighting Progam, 800.450.4454; Jerry Simmons, Sandia National Laboratory, 505-844-8402; Suzar		
Notes	Price likely to come down in the long run; thus primarily a long-term measure.		

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APPENDIX B COMMERCIAL LED LIGHTING

L11b Commercial LED lighting

Description	Commercial LED for institutional entry, perimeter lighting and display lighting.		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET, ROB		
Basecase Information:			
Description	Halogen PAR Lamp		
Efficiency	75	watts w/ 1050 lumens or 14 LPW	
Electric use	274	kWh/year	Assumes10 hours/ day for comm usage for 365 days/yr
Summer peak demand	0.062	kW	
Winter peak demand	0.056	kW	
Gas/fuel use			
New Measure Information:			
Description	White LED Lamp		
Efficiency	26.25	Watts @ 40 LPW	
Electric use	96	kWh/year	Assumes 10 hours/ day for comm usage for 365 days/yr
Summer peak demand	0.022	kW	
Winter peak demand	0.019	kW	
Gas/Fuel use			
Current status	PROTO/FLDTEST		
Date of commercialization	2004		
Life	6	years	or 20,000 hrs
Savings Information:			
Electricity	178	kWh/year	
Summer peak demand	0.040	kW	
Winter peak demand	0.036	kW	
Gas/Fuel		MMBTU/year	
Percent savings	65%		
Feasible applications	7%		Est. portion of commercial incandescent lighting for Landscape, Merchandise, Signage, Structure, Task
2020 Savings potential	17,429	GWh	
2020 Savings potential	176	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$53	2003 $	Currently at $.20/lumen. Estimated to go down to $.05/lumen by 2010
Other cost/(savings)	($6)	$/year	Avoided replacement costs, including labor
Cost of saved energy	$0.030	$/kWh	
Cost of saved energy	$2.93	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Incremental cost; thermal management; LED systems & components design		
Effect on utility	Less bulb changing		
Current promotion activity	PIER, DOE, Manufacturers selling to selected commercial/industrial reps		
Rating	3	(1-5)	
Rationale	Manufacturer support, but high cost; perceived as trendy & new		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Continue research on improving white color & raising LPW for white; develop business case; education for lighting designers, consumers		
Sources:			
Savings	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Peak demand	HMG 1999, PGE 2000		
Cost	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Feasible applications	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Measure life	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Other key sources	Sandy David-TCP, Inc. 330-995-6111; Vernica Martinez-LumiLeds, 408-435-6111		
Principal contacts	Judie Porter, 800.450.4454; Jerry Simmons, 505-844-8402; Suzanne Foster, 970-259-6802		
Notes	Price likely to come down in the long run; thus primarily a long-term measure.		

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